

HANDLING OVERSUBSCRIBED MESH PORTS WITH RE-TAGGING

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BACKGROUND OF THE INVENTION

10 Field of the Invention

The present invention relates generally to communication networks. More specifically, the present invention relates to network switches and switch-to-switch protocols.

15 Description of the Background Art

It is common in conventional computing environments to connect a plurality of computing systems and devices through a communication medium often referred to as a network. Such networks among communicating devices permit devices (or users of devices) to easily exchange and share information among the various devices. The Internet is a presently popular example of such networking on a global scale. Individual users attach their computers to the Internet, thereby enabling sharing of vast quantities of data on other computers geographically dispersed throughout the world.

25 Networked computing systems may be configured and graphically depicted in a wide variety of common topologies. In other words, the particular configurations of network communication links (also referred to as paths) and devices between a particular pair of devices wishing to exchange information may be widely varied. Any particular connection between two computers attached to a network may be direct or may pass through a large number of intermediate devices in the network. In addition, there may be a plurality of alternative paths through the network connecting any two network devices. Computing networks are therefore complex and vary in their configurations and topologies.

Certain network communication media and protocols are referred to as packet oriented. A protocol or communication medium may be said to be packet oriented in that information to be exchanged over the network is broken into discrete sized packets of information. A block of information to be

5 transferred over the network is decomposed into one or more packets for purposes of transmission over the network. At the receiving end of the network transmission, the packets are re-assembled into the original block of data.

In general, each packet includes embedded control and addressing information that identifies the source device which originated the transmission of
10 the packet and which identifies the destination device to which the packet is transmitted. Identification of source and destination devices is by means of an address associated with each device. An address is an identifier which is unique within the particular computing network to identify each device associated with the network. Such addresses may be unique to only a particular network
15 environment (i.e., a network used to interconnect a single, self-contained computing environment) or may be generated and assigned to devices so as to be globally unique in co-operation with networking standards organizations.

At the lowest level of network communication, such addresses are often referred to as MAC address (Media ACcess address). Network protocols
20 operable above this lowest level of communication may use other addresses for other purposes in the higher-level communication techniques.

In many conventional commercially-available network environments, the network communication medium is in essence a bus commonly attached to a plurality of devices over which the devices exchange. In
25 a simple networking topology, all devices may be attached to such a bus-structured common network medium. Any particular single network medium has a maximum data exchange bandwidth associated therewith. The maximum data exchange bandwidth of a medium is determined by a number of electrical and physical properties of the medium and protocols used to communicate over that
30 medium. For example, a popular family of related network media and protocols are collectively referred to as Ethernet. Ethernet defines a standard protocol for the exchange of messages over the communication medium. A variety of communication media are also defined as part of the Ethernet family. The

communication bandwidth of the Ethernet family of standards may change over time, but conventionally ranges from approximately 10 Mbit (megabits or million bits of information) per second to 1 Gbit (gigabits or billion bits of information) per second. Therefore, a single (slow) Ethernet connection, for example, has a
5 maximum data exchange bandwidth of approximately 10 Mbit per second.

In conventional network computing environments, a number of devices are used in addition to interconnected computing systems to efficiently transfer data over the network. Routers and switches are in general network devices which segregate information flows over various segments of a computer
10 network. A segment, as used herein, is any subset of the network computing environment including devices and their respective interconnecting communication links. As noted above, a single computer network communication link has a maximum data transfer bandwidth parameter defining the maximum rate of information exchange over that network. Where all devices on a computer
15 network share a common network medium, the maximum bandwidth of the computer network may be rapidly reached. The overall performance of the networked computing environment may be thereby reduced because information exchange requests may have to await completion of earlier information exchange requests presently utilizing the communication link.

It is often the case, however, that particular subsets of devices
20 attached to the network have requirements for voluminous communication among members of the same subset but less of a requirement for information exchange with other devices outside their own subset. Though standard switch features generally do not include identifying such logical groupings of devices,
25 some enhanced switching features do permit such logic to be performed within a switch device. For example, some enhanced switch features include the concept of defining and routing information based on virtual LAN (VLAN) definitions. In a VLAN, a group of devices may be defined as logically being isolated on a separate network although physically they are connected to a larger network of
30 devices. VLAN features of enhanced switches are capable of recognizing such VLAN information and can route information appropriately so that devices in a particular VLAN are logically segregated from devices outside the VLAN.

For example, the financial department of a large corporation may have significant information exchange requirements within the financial department but comparatively insignificant needs for data exchange with other departments. Likewise, an engineering group may have significant needs for data exchange within members (computing systems and devices) of the same engineering group but not outside the engineering group. There may in fact be multiple of such subsets of devices in a typical computing network. It is therefore desirable to segregate such subsets of devices from one another so as to reduce the volume of information exchange applied to the various segments of the computer network.

In particular, a switch device is a device that filters out packets on the network destined for devices outside a defined subset (segment) and forwards information directed between computing devices on different segments of a networked computing environment. The filtering and forwarding of such information is based on configuration information within the switch that describes the data packets to be filtered and forwarded in terms of source and/or destination address information (once address locations are "learned" by the switch(es)).

Network switch devices and protocols associated therewith are also used to manage redundant paths between network devices. Where there is but a single path connecting two network devices, that single path, including all intermediate devices between the source and destination devices, represent a single point of failure in network communications between that source and destination device. It is therefore common in network computing environments to utilize a plurality of redundant paths to enhance reliability of the network. Having multiple paths between two devices enhances reliability of network communication between the devices by allowing for a redundant (backup) network path to be used between two devices when a primary path fails.

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SUMMARY

One embodiment of the invention relates to a method of handling oversubscribed ports between switches. An oversubscribed port is detected at a

detecting switch. A set of paths exiting at the oversubscribed port is selected for retagging, and tags for the set of paths are invalidated. When packets with the invalidated tags are received, the received packets are retagged with a tag associated with a detour path.

5 Another embodiment disclosed relates to a packet switch apparatus with oversubscribed port handling capability for use in a switching mesh. The apparatus includes at least a plurality of ports and a switch controller coupled to the plurality of ports. The switch controller is configured using procedures stored in memory to (a) detect an oversubscribed port, (b) select a
10 set of paths exiting at the oversubscribed port for retagging, (c) invalidate tags for the set of paths, (d) receive packets with the invalidated tags, and (e) retag the received packets with a tag associated with a detour path.

 Another embodiment disclosed relates to a switching mesh including a capability to handle oversubscribed ports between switches. Each
15 switch in the mesh is configured to detect an oversubscribed port, select a set of paths exiting at the oversubscribed port for retagging, invalidate tags for the set of paths, receive packets with the invalidated tags, and retag the received packets with a tag associated with a detour path.

20 BRIEF DESCRIPTION OF THE DRAWINGS

 FIG. 1 is a flow chart depicting a prior method of handling oversubscribed ports.

 FIG. 2 is a schematic diagram of a switching mesh used in
25 discussing the prior method.

 FIG. 3 is a flow chart depicting a procedure for building an alternate path in the prior method.

 FIG. 4 is a schematic diagram depicting an exemplary switching mesh in accordance with an embodiment of the invention.

30 FIG. 5 is a diagram of a path tag in accordance with an embodiment of the invention.

 FIG. 6 is a schematic diagram of an example packet switch operable in accordance with an embodiment of the invention.

FIG. 7 is a flow chart depicting a method of oversubscribed port recovery in accordance with an embodiment of the invention.

FIGS. 8A and 8B depict an exemplary switching mesh used to discuss the method of oversubscribed port recovery in accordance with an
5 embodiment of the invention.

DETAILED DESCRIPTION

10 A. Prior Handling of Over-Subscribed Mesh Ports

FIG. 1 is a flow chart depicting a prior method **100** of handling oversubscribed ports. In this prior method, oversubscribed mesh ports (mesh ports that are dropping packets) are handled in a similar way as link failures. An oversubscribed mesh port is handled differently in that only a portion of the MAC
15 addresses associated with the link are moved to a newly built path. However, much like a link failure, these MAC addresses are temporarily put into a bit bucket state, such that packets destined to these MAC addresses will be dropped, in hardware circuitry, by the switch currently moving these addresses. The procedure of moving MAC addresses to a newly built path is a slow and
20 drawn out process that can take several seconds to complete in some implementations. There may be a large amount of packet loss during this period of time.

For purposes of illustration, consider the diagram of a switching mesh in FIG. 2. Let us say that host X is communicating with host Y. Switch A
25 **201-A** has assigned the path **202** from host X to host Y to traverse across the direct link that connects switch A, port 1 to switch B, port 4. If switch A detects **102** that its port 1 is oversubscribed, then switch A **201-A** selects **104** some of the MAC addresses to be moved to an alternate path **204** (which is yet to be built) so as to alleviate the oversubscription of port 1. In this instance, consider
30 that switch A **201-A** selects **104** the MAC address for host Y (MAC address Y), which is owned by switch B, to be moved to the alternate path **204**. Switch A then diverts **106** packets destined for the selected MAC address(es) (e.g., MAC address Y) to a "bit bucket". In other words, the packets destined for MAC

address Y are (temporarily) dropped. Switch A then builds **108** an alternate path **204** to switch B and assigns **110** the diverted MAC addresses (e.g., MAC address Y) to the alternate path **204**.

Building **108** the alternate path and assigning **110** the diverted addresses thereto involves a cumbersome procedure. Such a procedure **108/110** is now discussed in reference to FIG. 3 using the above example where switch A needs an alternate path to switch B. The procedure is as follows. Switch A searches **302** its path table and finds that its port 3 also leads to switch B. Switch A then sends **304** a request via port 3 to switch C asking whether switch C has a path to switch B. Switch C searches **306** its path table and finds that its port 9 leads to switch B. Hence, switch C returns **308** an acknowledgement via port 7 to switch A, and switch A assigns **310** the diverted MAC addresses (in this instance, MAC address Y) to port 3. In addition, since switch C does not have a direct path to switch B, switch C sends **312** a request via port 9 to switch D asking whether switch D has a path to switch B. Switch D searches **314** its path table and finds that its port 10 leads to switch B. Hence, switch D returns **316** an acknowledgement via port 12 to switch C, and switch C assigns **318** the diverted MAC addresses (in this instance, MAC address Y) to port 9. Finally, switch D is directly connected to switch B, and so switch B assigns **320** MAC address Y to its port 10.

The above discussion in reference to FIG. 6 shows the tedious, error-prone, and slow nature of the procedure **108/110** to move a MAC address to a newly built path. As the above discussion indicates, one disadvantageous aspect relates to the moving of MAC addresses across several switches. When MAC addresses are moved, the initiator switch communicates with its neighbor switches in order to find an alternate path. If the neighbor switch is not directly connected to the destination switch, then the neighbor switch also needs to search for a path to the destination switch.

30 B. Switching Mesh and Path Tagging

FIG. 4 is a schematic diagram depicting a switching mesh in accordance with an embodiment of the invention. One example path **404** is shown in FIG. 4. This path **404**, designated in this instance as path 0xB382,

travels as follows: exits port 3 of switch A **402-A**; enters port 7 of switch C **402-C**; exits port 8 of switch C **402-C**; enters port 5 of switch B **402-B**; exits port 6 of switch B **402-B**; and enters port 10 of switch D **402-D**.

In accordance with an embodiment of the invention, mesh tagging
5 is utilized to advantageously identify paths within the mesh from a source switch to a destination switch. In one implementation, each source/destination pair may be configured with up to fifteen different paths. This is because four bits are used for the path identifier in a path tag and the zero value is considered invalid in this specific implementation. One example of such a path tag is described
10 further below in relation to FIG. 5. Other embodiments may provide a different number of broadcast paths per switch by using a different number of bits for the path identifier. For example, if the path identifier has six bits, then each source/destination pair may be configured with sixty-three different paths.

FIG. 5 is a diagram of a path tag in accordance with an
15 embodiment of the invention. The path tag includes a source switch identifier **502**, a destination switch identifier **504**, and a path identifier **506**. The source switch identifier may also be called an owner switch identifier. In this embodiment, the path tag is sixteen bits in length. In particular, the source switch identifier **502** is six bits long, the destination switch identifier **504** is six bits
20 long, and the path identifier **506** is four bits long. In this implementation, with the switch identifiers being six bits long, sixty-three different switches in the mesh may be distinguished and identified. (The value zero for the switch id being considered an invalid value in this implementation.) With the path identifier being four bits long, fifteen different paths may be identified per
25 source/destination pair. (The value zero for the path id again being considered invalid in this implementation.) Other embodiments may have other lengths for these fields, resulting in different numbers of identifiable switches and paths.

Consider, for example, the mesh depicted in FIG. 4. Path tags of the format depicted in FIG. 5 may be used to identify different paths, for
30 instance, from switch A to switch D. Given that source and destination, each path tag would include an identifier corresponding to switch A in the source switch identifier field **502** and an identifier corresponding to switch D in the

destination switch identifier field **504**. Distinctive path identifiers, one per path between A and D, would be included in the path identifier field **506**.

For instance, a first path may go directly from A to D by exiting port 2 of switch A and entering port 11 of switch D. A second path may travel from A to D via switch C by exiting port 3 on switch A, entering port 7 of switch C, exiting port 9 of switch C, and entering port 12 of switch D. And so on for other possible paths. Each path is associated with a unique path identifier.

Consider the case where switch D learns a new MAC address and informs the rest of the mesh of the new MAC address associated with switch D. Switch A can then assign to that MAC address a path tag corresponding to one of the aforementioned paths from A to D (for example, path tag 0xB382 discussed above). Subsequently, every packet destined for that MAC address that enters switch A may be forwarded through the mesh based on that assigned path tag.

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C. Example Packet Switch

FIG. 6 is a schematic diagram of an example packet switch **600** operable in accordance with an embodiment of the invention. The specific configuration of packet switches used will vary depending on the specific implementation.

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A central processing unit (CPU) **602** performs overall configuration and control of the switch **600** operation. The CPU **602** operates in cooperation with switch control **604**, an application specific integrated circuit (ASIC) designed to assist CPU **602** in performing packet switching at high speeds required by modern networks.

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The switch control **604** controls the "forwarding" of received packets to appropriate locations within the switch for further processing and/or for transmission out another switch port. Inbound and outbound high speed FIFOs (**606** and **608**, respectively) are included with the switch control **604** for exchanging data over switch bus **652** with port modules. In accordance with an embodiment of the invention, the switch control ASIC **604** is configured to insert, remove, and analyze a path tag within a fixed location in a packet.

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Memory **610** includes a high and low priority inbound queue (**612** and **614**, respectively) and outbound queue **616**. High priority inbound queue **612** is used to hold received switch control packets awaiting processing by CPU **602** while low priority inbound queue **614** holds other packets awaiting
 5 processing by CPU **602**. Outbound queue **616** holds packets awaiting transmission to switch bus **620** via switch control **604** through its outbound FIFO **608**. CPU **602**, switch control **604** and memory **610** exchange information over processor bus **652** largely independent of activity on switch bus **620**.

The ports of the switch may be embodied as plug-in modules that
 10 connect to switch bus **620**. Each such module may be, for example, a multi-port module **618** having a plurality of ports in a single module or may be a single port module **636**. A multi-port module provides an aggregate packet switch performance capable of handling a number of slower individual ports. For example, in one embodiment, both the single port module **636** and the multi-port
 15 module **618** may be configured to provide, for example, approximately 1 Gbit per second packet switching performance. The single port module **636** therefore can process packet switching on a single port at speeds up to 1 Gbit per second. The multi-port module **618** provides similar aggregate performance but distributes the bandwidth over, preferably, eight ports each operating at speeds, for example, of
 20 up to 100 Mbit per second.

Each port includes high speed FIFOs for exchanging data over its respective port. Specifically, each port, **620**, **628**, and **637**, preferably includes an inbound FIFO **622**, **630**, and **638**, respectively for receiving packets from the network medium connected to the port. Further, each port **620**, **628**, and **637**,
 25 preferably includes a high priority outbound FIFO **624**, **632**, and **610**, respectively, and a low priority outbound FIFO **626**, **634**, and **642**, respectively. The low priority outbound FIFOs are used to queue data associated with transmission of normal packets while the high priority outbound FIFO is used to queue data associated with transmission of control packets. Each module (**618**
 30 and **636**) includes circuits (not specifically shown) to connect its port FIFOs to the switch bus **620**.

As packets are received from a port, the packet data is applied to the switch bus **620** in such a manner as to permit monitoring of the packet data

by switch control **604**. In general, switch control **604** manages access to switch bus **620** by all port modules (i.e., **618** and **636**). All port modules "listen" to packets as they are received and applied by a receiving port module to switch bus **620**. If the packet is to be forwarded to another port, switch control **604**
 5 applies a trailer message to switch bus **620** following the end of the packet to identify which port should accept the received packet for forwarding to its associated network link.

D. Over-Subscribed Mesh Port Recovery with Re-tagging

10 FIG. 7 is a flow chart depicting a method of handling oversubscribed mesh ports in accordance with an embodiment of the invention. This technique differs substantially from the prior technique. Advantageously, this technique avoids the need to search and build a new path for the MAC addresses being diverted to alleviate the oversubscribed port condition. Instead,
 15 the mesh switch that identifies the oversubscribed mesh port chooses a set of tags to be retagged in order to stop or at least reduce the amount of packet loss occurring from the oversubscribed condition.

As described above, by using mesh tagging (i.e. tags identifying different paths through the mesh), each switch may maintain a set of multiple
 20 paths to each of the other switches in the mesh. For example, in one implementation described above, each mesh switch may maintain a set of up to 16 identified paths to each of the other mesh switches.

For purposes of illustration, consider the switching mesh and tagged paths depicted in FIGS. 8A and 8B. Let us say that source host X is
 25 communicating with destination host Y. The packets from host X enter the switching mesh on non-mesh port 11 of switch A **402-A**. Switch A looks up host Y's MAC address in its hardware table and finds that path tag 0xB285 is associated with host Y. Switch A inserts the path tag 0xB285 into the packet and looks at the hardware table to see that port 3 is the exit port associated with
 30 that tag. As shown in FIG. 8A, the path **802** associated with tag 0xB285 traverses the switching mesh from switch A **402-A** (exiting mesh port 3), to switch C **402-C** (exiting mesh port 9), to switch D **402-D** (exiting mesh port 10), and finally to switch B **402-B**. A mesh port is a port to a link going between two

mesh switches. When switch B (the destination switch) receives the tagged packet, switch B checks its hardware table and determines that this tag 0xB285 terminates on itself (i.e. terminates at switch B). Hence, switch B strips out the path tag from the packet and forwards the packet (without path tag) on the
 5 appropriate non-mesh port (port 12, in this instance).

Switches C **402-C** and D **402-D** are intermediate switches along that original path **802** to switch B **402-B** (the destination switch). The following discussion considers an example wherein switch C **402-C** has the oversubscribed mesh port (port 9 of switch C).

10 When switch C detects **702** that its mesh port 9 is oversubscribed (for example, due to port 9 dropping packets), then switch C **402-C** selects **704** a set of paths from amongst the paths going from switch A (the owner switch) to switch B (the destination switch). This set of paths includes those paths to be retagged with tags for paths originating from switch C (the detecting switch) and
 15 destined for switch B (the destination switch). In this instance, consider that switch C **402-C** selects **704** the path with tag 0xB285 **802** to be retagged. Switch C (the detecting switch) then informs **706** switch A (the owner switch) of the set of tags that is going to be retagged.

Switch A (the owner switch) may then begin moving **708** some (or
 20 all) of MAC addresses associated with the path(s) that are going to be retagged. As discussed above, moving MAC addresses is a relatively slow and cumbersome process.

Meanwhile, in order to avoid or substantially reduce packet loss during the moving of MAC addresses by switch A, switch C determines **710** a
 25 detour path **804** (or detour paths) with associated path tag(s). For example, the detour path **804** may correspond to the direct path from switch C (port 8) to switch B (port 5) with path tag 0xA531, as shown in FIG. 8B.

Switch C (the detecting switch) invalidates **712** tags for the set of paths to be retagged. In our example, the tag 0xB285 **802** is invalidated. When
 30 switch C (the detecting switch) receives **714** packets with the invalidated path tag(s), switch C retags **716** these packets with a tag for a detour path (or with tags for more than one detour path).

Note that while the specific instance discussed above involves retagging packets from a single owner switch, packets from more than one owner switch may be retagged to the detour path(s).

Further note that, in accordance with a preferred embodiment, a
5 two-mode operation may be implemented. When an oversubscribed port is detected **702**, a determination is first made as to the number of tags associated with that port.

In a first mode, if the number of tags is large, then some of the tags are changed (retagged) by the detecting switch to a new path tag, and the owner
10 switch(es) of the changed tags are informed that their tag is no longer being used.

In a second mode, if there are not that many tags associated with the oversubscribed port, then the detecting switch does not do the retagging. Instead, the detecting switch chooses a tag or set of tags and informs the owner
15 switches of the oversubscription condition. When the owner switches receive this notification, they reassign one or more of the MAC addresses associated with those tags to new, less costly path tags.

In addition to the steps shown in FIG. 7, the detecting switch may also be configured to send a cost update message to other switches in the mesh
20 that initiate tags containing the oversubscribed port. The cost update message may contain the delta cost (i.e. the change in cost) for the tag. The delta cost may be calculated from the difference between the current cost added by the switch and the previous cost added by the switch. When a switch receives this delta cost relating to a tag that it initiates, the receiving switch adds the delta cost
25 to the current cost for the tag in order to update it. In this manner, a port that is oversubscribed becomes known as more costly in an advantageously immediate fashion rather than having to wait for a periodic recalculation of such costs. The more immediate updating of the tag costs allows for more appropriate load balancing to be performed. (Note that, in one implementation, the cost may be a
30 function of link speed, outbound queue depth, inbound queue depth, and number of dropped packets. Since measurements of these factors may be performed at polled intervals, the calculated cost will typically be smoothed using an algorithm that gives more weight to the current measurement.)

In the above description, numerous specific details are given to provide a thorough understanding of embodiments of the invention. However, the above description of illustrated embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise forms disclosed. One
5 skilled in the relevant art will recognize that the invention can be practiced without one or more of the specific details, or with other methods, components, etc. In other instances, well-known structures or operations are not shown or described in detail to avoid obscuring aspects of the invention. While specific embodiments of, and examples for, the invention are described herein for
10 illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

These modifications can be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the
15 specification and the claims. Rather, the scope of the invention is to be determined by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.